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Research Article

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Metal Ions Released During Canine Retraction Using Fixed Orthodontic Appliance: Prospective Clinical Study

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Abstract
Background: Metal ions released from dental alloys pose a significant concern due to their potential local and systemic effects. One of these effects is hypersensitivity, particularly associated with nickel-containing dental alloys. **Aims:** to measure metal ion concentration in saliva during orthodontic space closure on a 0.019X0.025 working archwire. **Material and Methods: Trial design:** Controlled clinical trial. **Setting:** Orthodontic treatment was provided at the Postgraduate Orthodontic Teaching Clinics and saliva testing was performed at the Faculty of Chemical Engineering/ Jordan University of Science and Technology (JUST). **Methods** Participants and interventions: Twenty-eight participants with bimaxillary proclination requiring extraction of all first premolar teeth participated in this study. Teeth alignment started with 0.014-inch nickel titanium (NiTi) archwire, then with a sequence of 0.018-inch, 0.016X0.022-inch, and 0.019X0.025-inch NiTi archwires, before 0.019X0.025-inch Stainless Steel (SS) rectangular archwire was reached. Patients were monitored monthly for a period of three months. Three unstimulated saliva samples were collected from each patient; before the commencement of treatment (T0), when 0.019X0.25-inch SS archwire was reached before space closure (T1), and one month after space closure (T2). Ion concentration in saliva samples was measured using an inductively coupled plasma mass spectrometer (ICP-MS). **Results:** Before treatment, iron concentration (53 Fe and 54 Fe) averaged 197.05 (64.35) mg/L and 425.48 (164.43) mg/L, respectively. Iron concentration increased during the alignment stage of orthodontic treatment ($P<0.05$) with no significant increase during space closure ($P>0.05$). Other investigated ions (Cr, Co, Ni, and Ti) did not show significant changes during orthodontic treatment ($P>0.05$). **Conclusions:** There was no increase in the metal ions concentration (Fe, Cr, Ti, and Ni) during space closure using a 0.019X0.025 working archwire and the Fe ion concentration increased in the initial stages of orthodontic treatment. Trial registration: ClinicalTrials.gov Identifier: NCT04549987

Keywords:
Metal release; Orthodontic appliance; Corrosion; Saliva

1. Introduction

Corrosion during orthodontic treatment is defined as the loss of metal or its conversion to an oxide which takes place in the oral cavity. In the oral environment, orthodontic appliances (brackets and archwires) are in constant exposure to conditions such as pH and temperature variations, mechanical fatigue, and the potential for alloy corrosion. Consequently, metal ions are released from these fixed appliances due to electro-galvanic currents, facilitated by saliva, leading to gradual corrosion throughout orthodontic treatment [1,2]. The intrinsic variety of metal al-

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loys, their usage with other alloys, micro-conversion, the strains placed on the appliances, and the friction between wires and brackets are some of the elements that might accelerate the corrosion process [3].

Orthodontic appliances are made from austenitic stainless steel (SS), containing approximately 8% to 12% nickel, 17% to 22% chromium, and other metals. The metal ions from SS alloy include nickel (Ni), copper (Cu), chromium (Cr), and iron (Fe). In contrast, alloys that contain nickel-titanium (NiTi) release both nickel (Ni) and titanium (Ti). The concentration of these ions may change during the different stages of orthodontic treatment [4]. Due to the metal ions' local and systemic toxic, immunogenic, mutagenic, and chemotactic properties, the release of metal ions from dental alloys is a significant problem. One of these hazardous effects is hypersensitivity, in particular, from nickel-containing dental alloys. There are few case reports documenting hypersensitivity to metals in fixed orthodontic appliances [5,6]. Other hazardous effects caused by nickel and chromium are dermatitis and asthma [7].

Many analytical methods can be used to assess the release of metal ions from orthodontic appliances. These include atomic absorption spectrophotometry (AAS), graphite furnace (GF)-AAS, inductively coupled plasma (ICP)-atomic emission spectroscopy (AES), and inductively coupled plasma mass spectrometry (ICP-MS) spectrometry [4].

ICP-MS is well-known for its capacity to identify a variety of non-metals and metals in liquid samples at low concentrations. It is a flexible labeling tool, as it can identify multiple isotopes of the same element.. In the literature, several studies on metal ion release during orthodontic treatment have been conducted before, however, they differed in the material tested, study design, and the tested ions. To the best of current knowledge,, no previous study was conducted to investigate the metal ions concentration during upper canine retraction using 0.019X0.025 SS archwire. Therefore, this clinical study was conducted to measure metal ion concentration in saliva during orthodontic space closure using a 0.019X0.025 working archwire.

2. Materials and Methods

2.1. Study Design

This study is a prospective clinical trial in which orthodontic treatment was provided to participants to measure metal ion concentration in saliva during orthodontic space closure using a 0.019×0.025 working archwire.

2.2. Setting

Orthodontic treatment was provided at the postgraduate orthodontic teaching clinics at the Faculty of Dentistry and saliva testing was performed at the Faculty of Chemical Engineering/ Jordan University of Science and Technology (JUST).

2.3. Ethics Committee Approval and Consent to Participate

The Jordan University of Science and Technology and King Abdullah University Hospital's Research Ethical Committee (IRB) evaluated and approved the study (Ref. 107/118/2018).

Participants for this study were recruited from new patients attending postgraduate orthodontic clinics. All participants or their guardians signed a written consent form.

Inclusion criteria included: age $\geq$ 16 years, bimaxillary proclination malocclusion with the need for upper first premolars extraction, average lower facial height and maxillomandibular plane angle, good oral hygiene, and healthy periodontium. Exclusion criteria were diseases and medications that were likely to affect bone biology, previous orthodontic treatment, and smoking.

2.4. Sample Size

To determine the sample size, the G* power 3.1.9 software was utilized [8]. Power analysis estimated a total sample size of 20 participants, with a conventional alpha level of 0.05 and a desired power (1-ß) of 0.80, assuming a small effect size of 0.3 across groups. With a 10% overall attrition rate, the initial recruitment effort should aim to include 22 individuals in total.

2.5. Participants and Eligibility Criteria

This study was conducted as part of a larger research proposal to study the effect of intra-oral aging of SS archwires on the speed of space closure [9]. Twenty-eight patients (mean age 18.92 ± 2.89 years) met the inclusion criteria and were asked to take part in the study. The included participants were treated by first premolar teeth extraction (upper and lower) using fixed appliances. Table 1 displays the inclusion and exclusion criteria for the study participants.

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Table 1: Means, SD, differences between means for ions released during the measured time points.

	T0 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T0–T1 Mean Diff (SE)	T2–T1 Mean Diff (SE)	T2–T0 Mean Diff (SE)
52Cr	18.18 (3.54)	20.47 (10.63)	18.60 (3.54)	2.28 (2.25)	−1.86 (2.28)	0.42 (0.68)
53 Cr	17.64 (3.22)	20.83 (15.89)	18.00 (3.56)	−3.19(3.32)	−2.83 (3.37)	0.37 (0.67)
54 Fe	197.05 (64.35)	243.37 (108.51)	247.70 (199.35)	−46.32 (16.89)*	4.33 (31.27)	50.66 (38.08)
57 Fe	425.48 (164.43)	521.57 (231.32)	526.69 (316.91)	−96.08 (33.10)*	5.12 (55.83)	101.20 (45.64)*
58 Fe	6.97 (1.83)	8.45 (5.68)	7.53 (2.91)	−1.45 (1.18)	−0.92 (1.23)	0.56 (0.55)
59 Co	0.61 (0.26)	0.71(0.50)	0.69 (0.29)	−0.10 (0.9)	−0.03 (0.11)	0.08 (0.06)
60 Ni	7.75 (2.11)	9.98 (11.57)	7.76 (2.27)	−2.22 (2.43)	−2.22 (2.42)	0.004 (.048)
62 Ni	15.51(3.42)	17.94 (11.77)	16.64 (5.79)	−2.42 (2.52)	−1.30 (2.67)	1.12 (1.06)
205 Ti	0.01 (0.006)	0.01(0.007)	0.01(0.006)	−0.001 (0.001)	0.00 (0.001)	0.001 (0.001)

T0: before the commencement of treatment, T1: when 0.019X0.25-inch SS archwire was reached before space closure, T2: one month after space closure.

2.6. Intervention

2.6.1. Orthodontic Intervention

All patients exhibited Class I skeletal malocclusion with bimaxillary proclination, a Class I canine relationship, mild upper and lower arch crowding, average lower facial height (LFH), and Max/Mand angle. All patients were treated by the same clinician (RA/orthodontic postgraduate student) using pre-adjusted edgewise fixed appliance (3M Gemini Uniteks, 0.022-inch MBT prescription brackets). Teeth alignment started with a 0.014-inch NiTi archwire, followed by a progression through 0.018-inch, 0.016x0.022-inch, and 0.019x0.025-inch NiTi archwires, before transitioning to a 0.019x0.025-inch SS rectangular archwire. An elastomeric power chain, spanning from the first molar to the first molar was used to close extraction spaces. All patients were reviewed within a 4-week interval.

2.6.2. Saliva Sampling and Ion Concentration Measurement

Unstimulated saliva samples were collected from each patient at different time points; before orthodontic treatment (T0), when working archwire (0.019X0.25-inch SS) was reached immediately before space closure (T1), and one month after space closure (T2).

Participants were instructed to fill a polypropylene container with 3 mL of saliva. Each container was labelled with the subject's code and the date of the sample and stored in a -40 °C refrigerator. The collected samples were moved to a -20 °C refrigerator and then allowed to melt at room temperature. For the digestion process, 1mL of saliva was collected from each sample and transferred to a special tube for the digestion process, then 3mL hydrogen peroxide and 7mL nitric acid were added. The digestion was done using the Milestone microwave digestion system. After digestion of the samples, each sample was transferred to a 10mL beaker, and then evaporated at 120 °C. The samples were reconstituted using 1% HNO3 and filtrated to reach 10mL volume. Digested samples were stored at -20 °C overnight and then sent for analysis the next day. Ion concentration was measured using an ICP-MS.

2.7. Outcome

The concentration of 52-Cr, 53-Cr, 54-Fe, 57-Fe, 58-Fe, 59-Co, 60-Ni, 62-Ni, and 205-Ti ions in milligrams/Liter (mg/L) was measured at three-time intervals; (T0), (T1) and (T2).

3. Statistical Methods

Statistical analysis was performed using SPSS software (SPSS 23, SPSS Inc., Chicago, USA). Means and standard deviations were calculated for the concentration of the tested ions. A repeated measures ANOVA test was performed within each group to determine the ion concentration change at the different time points. The P-value was set at 0.05 level.

4. Results

Table 1 shows the mean, standard deviation (SD), the difference between mean, and standard error (SE) of mean difference for the studied ions that were released during the three-time intervals. Before treatment, iron concentration (53 Fe and 54 Fe) averaged 197.05 (64.35) mg/L and 425.48 (164.43) mg/L, respectively. Iron concentration increased during orthodontic treatment; this increase was significant (P<0.05). Other investigated ions (Cr, Co, Ni, and Ti) did not show significant changes during orthodontic treatment (P>0.05).

5. Discussion

Ion release from orthodontic appliances into saliva has been widely documented in the literature. Amini et al. [10] and Matos de Souza [11] detected double concentrations of cobalt and nickel ions and 20% higher levels of chromium in the saliva of orthodontic patients with fixed appliances compared to the control group. However, no significant differences were reported for cobalt (Co) and chromium (Cr) levels [10].

In the current study, the concentration of the investigated ions increased and reached the highest levels in the first month after placement of the appliance. However, this increase was insignificant and decreased back to their level before orthodontic treatment. This finding aligns with Imani et al., who noted in their systematic review that salivary concentrations of nickel and chromium were raised due to corrosion of fixed orthodontic equipment at the commencement of orthodontic treatment; however, these higher concentrations eventually recovered to their starting values [12].

Sallam [13] stated that metal ions released in patients with fixed orthodontic appliances are at quantifiable levels that are deemed acceptable. Furthermore, this was consistent with the findings of Velasco-Ibáñez et al. [14] who found that when peak metal release (Ni and Ti) in the saliva is reached (three months after placement of a fixed orthodontic appliance), the concentrations are within acceptable limits.

In the current study, iron (Fe) concentration before orthodontic space closure was increased. A significant change in the concentration of iron was observed between T1-T2 and T1-T3 intervals. This means that iron concentration increased after placing the orthodontic appliance until 0.019X0.025 -inch SS archwire was reached. This may be due to the corrosion of orthodontic appliances and their components. This is similar to the results obtained by Frois et al. [15] The limitations of this study include the investigation of metal ion concentrations for only one month after space closure, and the absence of blood analysis alongside saliva analysis. This study provides evidence to support the safe use of 0.019X0.025 SS wire for orthodontic space closure. The use of such a wire ensures controlled tooth movement and is not associated with an increase in metal ions in saliva.

6. Conclusions

- There was an increase in the salivary Fe ion concentration during the early stage of orthodontic treatment but not during space closure using 0.019X0.025 SS archwire.
- No significant changes in the salivary Cr, Ti, and Ni ions concentrations during all stages of orthodontic treatment.

List of Abbreviations

JUST	Jordan University of Science and Technology
ICP-MS	Inductively coupled plasma mass spectrometer
Cu	Copper
Cr	Chromium
Fe	Iron
Ni	Nickel
Ti	Titanium
NiTi	Nickel-titanium
AAS	Atomic absorption spectrophotometry
GF	Graphite furnace
ICP	Inductively coupled plasma
AES	Atomic emission spectroscopy
IRB	Institutional Review Board
Mg/L	Milligrams/Liter

Author Contributions

Conceptualization, E.A., R.A. and S.A.; methodology, R.A., A.B., E.A.; validation, E.A. and A.B.; formal analysis, E.A.; investigation, R.A.; resources, R.A.; data curation, R.A.; writing—original draft preparation, R.A. and E.A.; writing—review and editing, E.A., R.A., and S.A.; supervision, E.A., S.A. and A.B.; project administration, E.A.; funding acquisition, E.A.

Availability of Data and Materials

Data related to this study will be made available upon reasonable request.

Human Rights Statement

The study was conducted following the Declaration of Helsinki and was approved by the Jordan University of Science and Technology and King Abdullah University Hospital's Research Ethical Committee (IRB) [Ref No. 107/118/2018]

Consent for Publication

All authors and participants of the study have given consent for the publication of this article. No personal images or identifiable information of the participants are included in this article.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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